Abstract

Head injuries caused due to an occupant's head striking the upper interior surfaces of a vehicle during an accident is a major concern in automotive safety In USA, studies have shown that even with dynamic safety standards such as for front and side impact in place, head impact related injuries during a crash are a major cause of fatalities To address this problem, the National Highway Traffic Safety Administration (NHTSA) introduced a regulation that focuses on providing head impact protection in relation to practically the entire upper interior of a vehicle The regulation came into full force in 2003 and was included as an amendment to the previously existing FMVSS 201 standard for head impact safety against instrument panel According to the new standard which applies to all vehicles with a GVWR (Gross Vehicle Weight Rating) not exceeding 10000 lbs (4545 kg), HIC(d) (Head Injury Criterion, dummy) should not exceed 1000 when an interior target is impacted with a free-motion featureless Hybrid III headform with a velocity of 15 mph (6 7 m/s)

A pedestrian can suffer head injury due to his head hitting the exterior surface of hood/bonnet of a car after his lower body is hit by the front of the car As this is a leading cause of severe to fatal injuries amongst pedestrians in Europe, cars in this geographical region are being now assessed for pedestrian head impact safety under the EuroNCAP program Typically, this evaluation is made after impacting exterior of hoods of vehicles with given spherical adult and child headforms of mass 4 8 kg and 2 5 kg respectively and ensuring that the computed HIC_{15} based on acceleration responses of the headforms should not exceed 1000 for obtaining a "Good" rating

In countries such as India where the number of two-wheelers such as scooters, mopeds and motor-bikes is substantial when compared with other vehicular modes of

transportation, a large number of fatalities due to head impact is suffered by the users of these vehicles (i.e. two-wheelers). Minimizing the head injury risk of these road-users is a significant challenge as the degree of protection offered by helmets that are currently available is not clear. Mandatory usage of helmets by two-wheeler riders is not enforced in most Indian cities by raising doubts on the effectiveness of helmets based on incomplete information on head injuries suffered by helmet-wearers.

It is apparent from the above discussion that there is a crying need for protecting various road users from head impact by implementing countermeasures in the interior and exterior of vehicles, and through improved design of helmets. From an engineering standpoint, the design of efficient head impact protection solutions calls for advanced computer-aided engineering (CAE) tools that can simulate the present class of problems of nonlinear contact-impact dynamics. The broad objective of the present research work, as the thesis title suggests, is the development of CAE-based design methodologies comprising lumped parameter and finite element modeling for designing, in an efficient manner, effective and optimized lightweight head impact countermeasures. The scope of the research undertaken and the tasks accomplished are briefly listed below.

- Enhancement of a previous lumped parameter model for simulation of headform impact by incorporating parabolic and piecewise linear unloading behaviors of spring countermeasure,
- Implementation of strain rate effect in the above lumped parameter model by allowing velocity-dependent spring behavior analogous to Johnson-Cook material modeling,

- Development and validation of a finite element model (for analysis with LS-DYNA) of the featureless Hybrid III headform employed in FMVSS 201 compliance testing for vehicle upper head impact safety,

- Further improvements in unloading behavior of a previous lumped parameter model with linear and rotational degrees of freedom, and development of a new methodology employing a combination of lumped parameter and finite element modeling for designing optimized vehicle upper interior head impact protection countermeasures such as trim with integrally molded ribs covering A-pillars,

- Demonstration of the ability of the two degree-of-freedom lumped parameter model in predicting headform rotation during impact by comparing against rotational responses yielded in finite element modeling-based simulation, providing insight into the adequacy of the existing linear acceleration-based injury criterion (e.g. HIC(d) not exceeding 1000 as per FMVSS 201 regulation) in relation to limiting gross rotational acceleration at headform CG (center of gravity),

- Demonstration of a new procedure for designing helmets by using the biofidelic Hybrid III headform used in FMVSS 201 compliance testing, and through extensive finite element analysis, establishing necessary helmet foam and shell attributes (strength, thickness, etc.) that will ensure that the HIC(d) threshold of 1000 is not exceeded when a headform-mounted helmet is dropped on a rigid surface with an impact velocity of 6 m/s